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A REVIEW ON LCEA OF INFRASTRUCTURE BUILDINGS

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ABSTRACT

The construction industry is one of the fastest growing and a major energy consuming sector, due to the increase in population and demands. Buildings demand energy in their life cycle from its construction to demolition stage. Life Cycle Energy is the total energy consumed during the overall life of a building. This paper focuses on assessing the life cycle energy of an infrastructure building. The three phases of the life cycle of a building are the manufacturing, use and demolition phases and this paper helps in identifying the phases that consume more energy and to develop strategies for its reduction and improvements. With the help of various local alternative materials, we can reduce the energy use for the operation to a very low level and suggestions are given on the alternative materials to be used. Results show that embodied and operational energy are the main contributors to the building's life cycle energy demand. Various tools are available for the calculation of operational energy which are discussed in detail. It is very important to consider the type of material, also, the service life of materials being used can have a significant effect on the total energy embodied in a building over its lifetime.

Key words: Building materials, Embodied Energy, Operational Energy, Lifecycle Energy, Lifecycle Energy Assessment, e Quest.

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1. INTRODUCTION

A large number of residential, commercial and office buildings are built every year all over the world. Construction of these buildings is the major exploiters of both renewable and non-renewable resources that are harmful to the environment. Energy is inseparable from the making of materials in the different phases such as their manufacturing, use, and disposal phases and most of the energy goes into the following three big sectors; transportation, buildings (heating, cooling, lighting, etc) and industry, including the production of materials [1]. The demand for energy in a building has two primary components; direct energy, and indirect energy. Direct energy is the energy consumed in onsite and offsite operations of a building during the construction stages, whereas indirect energy is the energy consumed in manufacturing the building materials used in its construction and technical installations [2]. The total life cycle energy of a building includes both embodied energy and operational energy [3,4,5]. Embodied energy is the total energy consumed in the life cycle stages of building and building materials, such as raw materials, extraction, transportation, manufacturing, assembly, installation, whereas operational energy is the energy required to operate the building in the process such as space conditioning, lighting and operating other building appliances. Nowadays, only operational energy has been considered contributing to its largest share in the total life cycle energy. But due to the introduction of energy efficient equipment and appliances, the potential for restricting the operational energy has increased, which resulted in including the embodied energy in building materials.

Life Cycle Energy Analysis focuses on energy as the only measure of the environmental impact of buildings and products. The purpose of LCEA is to present a more detailed analysis of energy attributable to products, systems or buildings, to compare and evaluate the embodied energy and operational energy in materials and components [6]. The objective of this review paper focuses on the evaluation of the energy consumption of all energy entries within the life of the energy cycle of buildings using the life cycle energy analysis and also enables to evaluate and state strategies designated for reducing energy consumption.

2. EMBODIED ENERGY

Buildings are constructed with wide selections of building materials, and each of these materials consumes energy throughout its different stages of use. Likewise, each building consumes energy during its life cycle in different stages, such as in raw material extraction, transport, manufacture, assembly, installation, disassembly, demolition, and disposal. The energy that is consumed in these different stages of a building is termed as Embodied Energy [7]. Usually, the energy that is available in limited amount should be considered as embodied energy [8]. It is important for all the stakeholders in the building industry to incorporate strategies at the feasibility and design stages of building to reduce the energy consumption associated with the building sector in order to reduce the greenhouse gas emissions and avoid the further degradation of the natural environment [9].

Recently, the importance of energy conservation research was on the operational energy of a building. Due to the introduction of energy efficient equipment and appliances along with more advanced and effective insulation materials, the potential for reducing operational energy has increased. As a result, the current emphasis has shifted to include embodied energy in building materials [10,11,12]. The manufacture of building components off-site accounts for 75% of the total energy embedded in buildings and due to the increased use of high energy intensive materials, it results in the increase of this share of energy [13,14,15]. The relative proportion of embodied energy in the total life cycle energy increases, as buildings become more energy efficient over time [16,17]. However, embodied energy can be reduced if low energy intensive materials are selected at the initial stages of building design.

In a case study of a Norwegian row house shows that the embodied energy for all the cases taken including the embodied energy in materials that are used throughout the lifetime for maintenance and for the replacement of the worn out components, the embodied energy increases with increasing insulation levels in the building envelope except in one case where the embodied energy for the building envelope is far higher due to the use of cellulose fibre insulation, which has a higher density [18]. A case study on a conventional building resulted that the embodied energy accounts for 2-38% of the total life cycle energy, whereas for a low energy building, it would range from 9-46% [19] and embodied energy for a low energy house could be equal to 40-60%of the total life cycle energy [20]. In heating dominated regions, embodied energy represents a relatively low percentage of total life cycle energy, which may not be the same for a moderate or cooling dominated regions due to the latter's relatively low operational energy [21]. Building materials with high embodied energy could result in more carbon dioxide emissions than materials with low embodied energy [22]. The embodied energy of a building is calculated using the existing values for energy intensity of the materials and components. The energy used in the production and assembly of components and energy for transportation of the materials to the building site is also included. Steel for nails, reinforcements is assumed to be recycled and steel for plates is assumed to be newly produced. Measuring operational energy is easy and less complicated when compared to embodied energy which is more complex and time-consuming. Currently, there is no method which is generally accepted and available to calculate embodied energy accurately and consistently [23]. But there are few various methods for embodied energy calculations which have been generally accepted which have been discussed below.

2.1. Process-Based Analysis

This is the oldest and still most commonly used method, involving the evaluation of direct and indirect energy inputs to each product stage. This process is based on the various processes involved in the manufacturing of the material/product. It usually begins with the final product and works backward to the point of raw material extraction. The magnitude of the incompleteness varies with the type of product or process and the depth of the study [24].

2.2. Input/Output Analysis

This method is based on monetary flows between sectors and can be transformed to physical flows to capture environmental fluxes between economic sectors. The number of sectors and their definition vary within each country. I/O analysis is subject to many uncertainties, mainly due to the high level of aggregation of products.

2.3. Hybrid Analysis

As the name indicates it is a combination of the above mentioned methods. It has the advantages of both the methods hence it can analyze the data with a more closed system boundary. In this method some of the parts are analyzed by process method and other parts are analyzed by I/O method.

Moreover, there has been a growing interest in adopting a lifecycle approach in current research, where research studies have used life cycle assessment to calculate embodied energy in buildings, building materials, and assemblies. Lifecycle assessment is an effective tool for measuring embodied energy in buildings, but one disadvantage is that it is data intensive and requires robust data [25]. The commonly used methods for a new building are hybrid methods as it can define and clear system boundary and hence the results are expected to give more close or accurate data compared to the other methods. Hybrid approaches, which capture much of the building through process method and use I/O method to fill in the '*gaps*',

have also been used [26]. It is not possible to use I/O method to assess the embodied energy of existing buildings, as I/O data tables are not available for the period in which these buildings were constructed. The embodied energy of an institutional building using alternate building material was studied. The research paper also includes the embodied energy calculation of a RCC framed structure and comparison of the embodied energy of the first and the later. Figure 1 shows the steps involved in their paper for calculating the embodied energy [27].

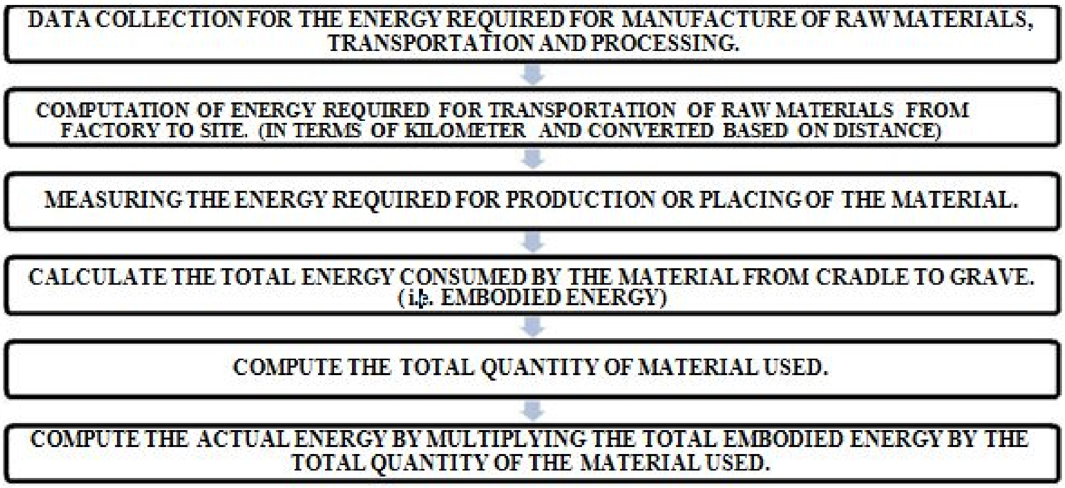

Figure 1 Steps for calculating the embodied energy

The following values of embodied energy were used by the authors for the calculation. Embodied energy of the basic building materials such as brick, blocks, stone, sand, steel, cement, crushed aggregates etc which are used in their calculation is tabulated in Table 2.1.

Table 1 Embodied energy of the building materials

Sl. No.	Material	Unit	Energy
1	Burnt Brick	MJ/No	3.75
2	Solid Concrete Block	MJ/m	12.98
3	Hollow Concrete Block	MJ/m	8.00
4	River Sand	MJ/m^3	29.58
5	Steel	MJ/m^3	226368
6	Cement	MJ/kg	3.60
7	Stone (virgin rock)	MJ/m^3	104.00
8	Crushed Stone Aggregate	MJ/m^3	215.80

Energy consumed by these materials for the transportation was also studied. Lead distance is the distance from purchasing place of the materials to the storage yard or to the site. The lead distance for each of the materials was considered for the calculation of transportation energy and was different for each material depending upon their availability. The embodied energy of the building was calculated and analyzed in the study and the distribution of embodied energy among the various construction materials were found to be

53% for steel, 16% for bricks/blocks, 21% for cement, 3% for sand and 2%for aggregates. The final values of total energies of materials used for the construction of the masonry structure and RCC framed structure was also studied and concluded that the Embodied energy consumption of RCC framed structure is much higher than that of Masonry structure. There are different parameters that not only define embodied energy but also control the quality of embodied energy data. The parameters responsible for the variation in embodied energy data are system boundaries, method of embodied energy analysis, geographic location, primary and delivered energy, age of data, data source, and manufacturing technology [28]. Buildings are responsible for 30-40% of energy use and associated with greenhouse gas emission worldwide with a significant share to the residential buildings [29].

Recurrent embodied energy is the energy involved in maintenance and refurbishment activities over a building's lifetime [30]. Recurrent embodied energy is directly affected by the service life of the building materials. The embodied energy which is linked with the replacement of the building materials can represent upto 32% of the initial embodied energy of a building [31]. Recurrent embodied energy was calculated based on the number of times each individual material would likely be replaced during the useful life of the building. Average material service life figures from the various literatures were assumed for this initial analysis [32]. When materials are poorly maintained and require replacement regularly, the recurrent embodied energy of a building may be as important as the embodied energy. Therefore, consideration of material choice is very important, so as to minimize the embodied energy of building life cycle and that it doesn't affect the operational energy demand.

3. OPERATIONAL ENERGY

Operational energy is the energy that includes the energy used for space heating and cooling, hot water heating, lighting, refrigeration, cooking and appliance and equipment operation. Space heating and cooling energy are often simulated using computer programs such as CHENATH, TRNSYS, and DOE2. Operational energy is one of the most important component in the life cycle energy of the building along with the initial embodied energy, recurrent embodied energy over its lifespan of the buildings [33]. Operational energy is the energy requirement of the building during its life from commissioning to demolition (not including maintenance or renovations). Operational Energy varies considerably with the climatic conditions and seasons, geographic location, using pattern, efficiency of equipment etc. Normally it possesses a linear relationship with the total energy. A study on life cycle energy analysis revealed that the operational energy can contribute nearly 89% of the total energy [34].

In residential or small buildings, generally major part of the operational energy is consumed by the space conditioning systems followed by domestic hot water then the lighting and other appliances [35,36]. It has been studied that the operational energy of the structures can be analyzed either by manually or through simulation techniques. Manual methods can be used only for buildings that are under operation and this method cannot be used for structures which either under construction or in the design stage. However, the operational energy of the buildings under design stage or under construction can be analyzed using energy simulation techniques. There are many energy simulation software available such as Ecotect, eQuest, Energy Plus, Open Studio etc [37]. The preference of the simulation program when compared to other simulation programs might depend upon the usability and applicability of the program to our need in different phases of a building's lifecycle. Therefore, eQuest is preferred than the other simulation tools.

eQuest is an energy simulation tool which can be used for the simulating the building performance and thereby calculating the operational energy. eQuest calculates the hour by hour energy consumption over an entire year using an hourly weather data for the location under consideration. It provides a very accurate simulation results related to the building's use of energy [38]. The operation interface of the eQuest software is depicted in Figure 2.

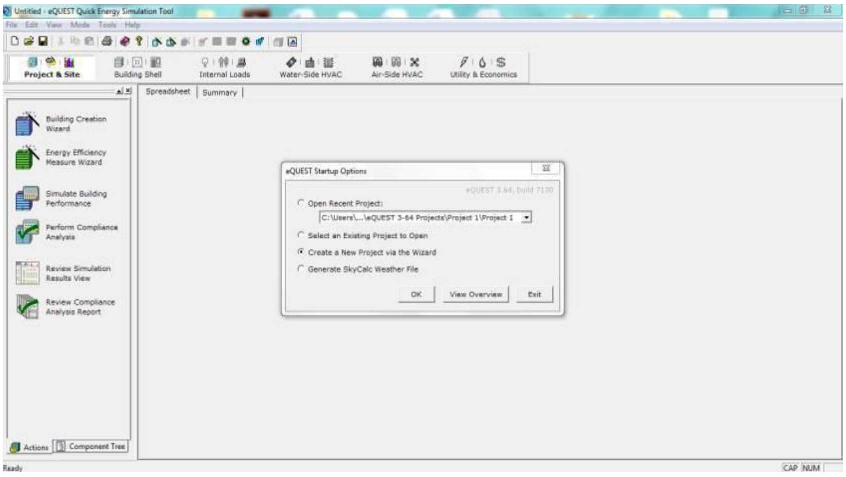

Figure 2 eQuest operation Interface

Figure 3 depicts the steps for simulating the model. eQuest also contains a dynamic day lighting model to assess the effect of natural lighting and thermal lighting demands.

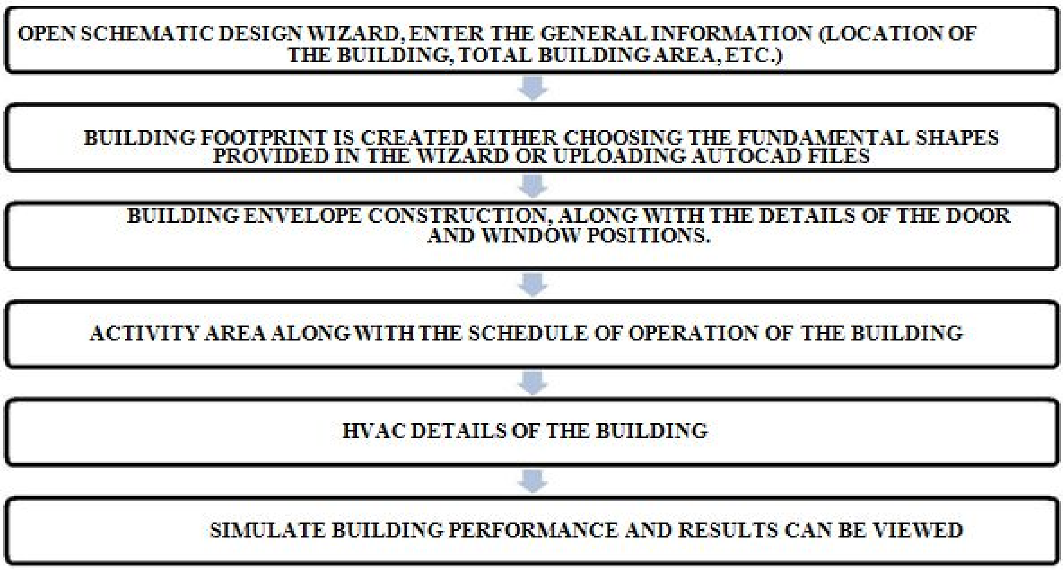

Figure 3 Steps for Simulating the Model

4. LIFE CYCLE ENERGY ANALYSIS (LCEA)

Buildings consume energy directly or indirectly in all phases of their life cycle, hence, they need to be analyzed from the life cycle point of view. The system boundaries of this analysis shown in Figure 4 below include the energy use of the following phases: manufacture, use, and demolition [39].

By performing LCEA, the phases that have the highest energy demand can be identified and targeted for improvements. Basically, LCEA is an approach that accounts for all the energy inputs to a building in its life cycle. For the demonstration of the life cycle benefits of

the strategies that have been designed to optimize the operational energy or embodied energy of a building, the LCEA concepts can be used. A Building's life cycle energy consists of its initial embodied energy, recurrent embodied energy and operational energy over its lifetime [33]. The following can be used for calculating the life cycle energy,

$$LCE = EEi + (EErec + OE) \times \text{building lifetime} \quad (1)$$

where: LCE = the life-cycle energy;

EEi =the initial embodied energy of building;

EErec = the annual recurrent embodied energy (for example, in maintenance)

OE = the annual operational energy

In LCEA, the embodied energy in a building and the operational energy of the building are calculated for the anticipated lifetime of the building. The application of LCEA can result in a significant net reduction in energy use over the projected lifetime of the building. In a building sector, a life cycle approach is the most appropriate method for the analysis of energy [40].

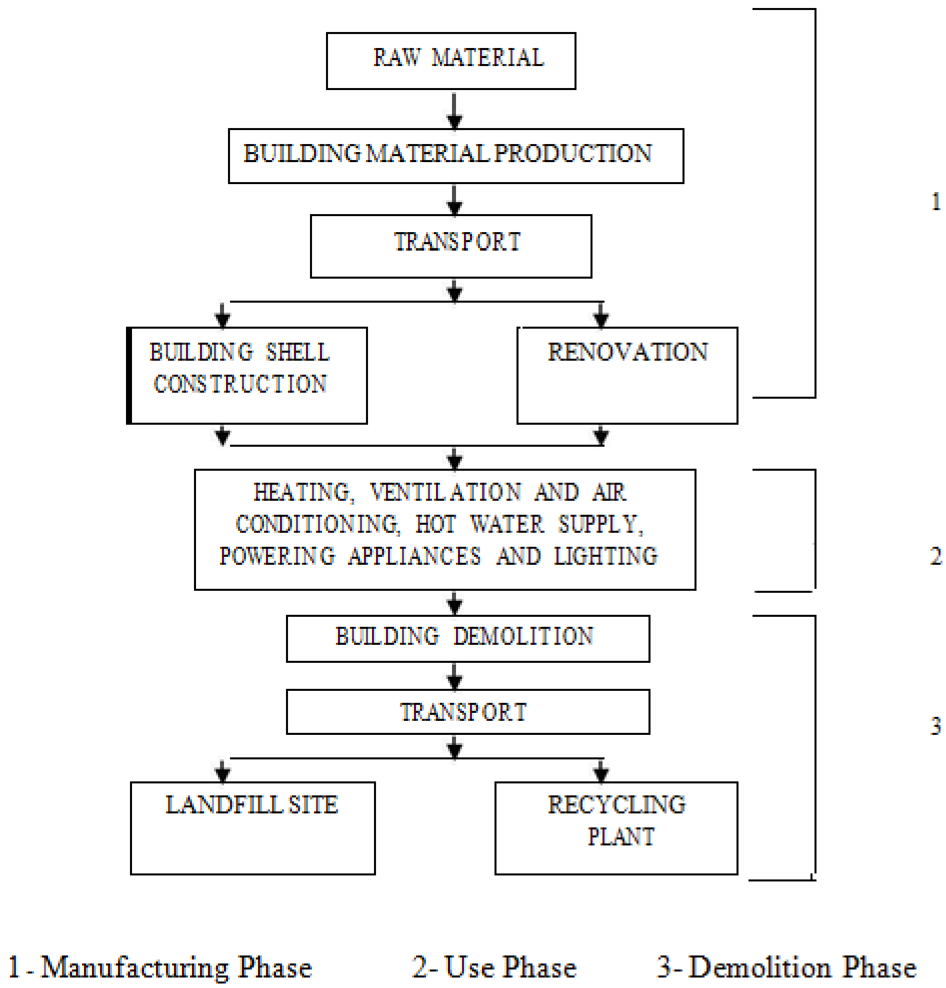

Figure 4 Life Cycle Energy of a building

A method for the calculation of the energy use during the life cycle of a building was presented. The paper had case studies of the total energy use for the single unit dwellings built in Sweden [41].Life cycle assessment is a tool for uniformly analyzing the environmental performance of products or processes over their entire life cycle, including raw

material extraction, manufacturing use and end-of-life disposal and recycling. Therefore, LCA is often considered a “cradle to grave” approach for the evaluation of environmental impacts [42,43]. The International Organization for Standardization (ISO) adopted an environmental management standard in the 1990s as part of its 14,000 standard series focusing on establishing methodologies for LCA [44].

LCA can be used for evaluating the energy consumption and the amount of energy used in a material’s useful life [45]. A variety of LCA tools are present in the form of software, along with datasets of environmental impacts of building materials. These tools such as ATHENA, BEES 4.0, Ecoinvent, Eco-Quantum, Envest 1, LICHEE, Sima PRO, etc. provide a user-friendly approach to determine the life cycle impacts of a building. However, most of these don’t cover all the stages of a building’s life cycle and none of these existing tools and datasets has the capability to perform a full life cycle assessment of a building [46,47].

Buildings are usually large in size, complex and unique in nature and their construction often involves the assembly manufactured materials and products. Buildings possess a greater life span than most of the other products. Now tracking and assessing such a long span, requires extensive effort in terms of data collection and interpretations. Unlike other manufactured products, building production processes are less consistent, making data collection a difficult task. The lack of reliable and the limited information allow energy and environmental impacts of a building and components slow down the LCA process for a building.

5. CONCLUSION

Buildings have a significant share in overall energy consumption and with the scope for future development there is an expectation for further growth in consumption. This study helps to find the energy consumption in the various phases. To attain sustainable construction, the main focus should be on reducing the overall energy consumption and many of the building materials have the promising potential of significantly reducing the energy use in construction industries. From this study we can conclude that the embodied energy can be also equivalent of many years of operational energy as, operational energy consumption depends on the occupants and embodied energy is not occupant dependent. Embodied energy content is incurred once whereas operational energy accumulates over time and can be influenced throughout the life of the building. Recycled materials and materials those with lower embodied energy and higher durability can be used as alternative materials in construction.

REFERENCES

[1] Ramesh T, Ravi Prakash, Shukla K.K, “Life Cycle Energy Analysis of buildings: An overview”, Journal of Energy and Buildings, Vol.42, 2010, pp.1592- 1600.

[2] Manish K Dixit, Jose L Fernández-Solís, Sarel Lavy and Charles H Culp,“Need for an embodied energy measurement protocol for buildings: A review paper”, Journal of Renewable and Sustainable Energy, Vol.16, 2012, pp.3730-3743.

[3] Santero NJ, Masanet E, Horvath A, “Life Cycle Assessment of pavements, Part I; Critical review”, Resources, Conservation, and Recycling, 2011, 9-10:801-9.

[4] Ozbay K, Jawad D, Parker NA, Hussain S , “Life-Cycle cost analysis”, Transportation Research Record, 2004, 1864:62-70.

[5] Santero NJ, Horvath A, “Global warming potential of pavements”, Environmental Research, 2009, 4:034011.

[6] Raymond J. Cole, Paul C. Kernan, “Life Cycle Energy use in Office Buildings”, Journal of Building and Environment, Vol.31, 1996, pp.307- 317.

[7] Ding G, “The development of a multi-criteria approach for the measurement of sustainable performance for built projects and facilities”, Ph.D. Thesis, University of technology, Sydney, Australia, 2004.

[8] Hegner S., “Embodied energy for energy efficiency measures, an assessment of embodied energy’s relevance for energy saving in the Swiss residential building sector”, Diploma Thesis, Department of Environment Science, ETH, Zurich, 2007. Switzerland.

[9] Rauf A, Crawford R.H, “The Effect of Material Service Life on the Life Cycle Embodied Energy of Multi-Unit Residential Buildings” World Sustainable Building, Barcelona Conference, 2014.

[10] G.A. Keoleian, S. Blanchard, P. Reppe, “Life-cycle energy, costs, and strategies for improving a single family house, Journal of Industrial Ecology, Vol.4 (2), 2014, pp.135–156.

[11] B. Hannon, R.G. Stein, B.Z. Segal, D. Serber, “Energy and labor in the construction sector” Journal of Science, Vol.202 (4370), 1978, pp.837–847.

[12] J. Nassen, J. Holmberg, A. Wadeskog, M. Nyman, “Direct and indirect energy use and carbon emissions in the production phase of buildings: an input output analysis, Energy, Vol.32 (9), 2007, pp.1593–1602.

[13] G. Ding, “The development of a multi-criteria approach for the measurement of sustainable performance for built projects and facilities”, Ph.D. Thesis, University of technology, Sydney, Australia, 2004.

[14] Y.L. Langston, C.A. Langsto, “Reliability of building embodied energy modeling: An analysis of 30 Melbourne case studies”, Construction Management and Economics, Vol.26 (2), 2008, pp 147–160.

[15] R. Spence, H. Mulligan, “Sustainable development and the construction industry”, Habitat International, Vol.19 (3), 1995, pp.279–292.

[16] Plank R, “The principles of sustainable construction”, The IES Journal Part A: Civil and Structural Engineering, Vol.1 (4), 2008, pp.301-7.

[17] Frey P, “Building reuse: finding a place on American climate policy agendas”, Washington DC: National Trust for historic preservation, 2008.

[18] Winther B.N, Hestnes A.G, “Solar versus Green: The analysis of a Norwegian row house”, Journal of Solar Energy, Vol.66, No.6, 1999, pp.387-393.

[19] Sartori I, Hestnes A.G, “Energy use in the life cycle of conventional and low energy buildings: A review article”, Journal of Energy and Buildings, Vol.39, 2007, pp.249-257.

[20] Thormak C., “Energy and resources, material choice and recycling potential in low energy buildings”, CIB Conference, SB 07 Sustainability Construction Materials and Practices, 2007.

[21] Nebel B, Alcorn A, Wittstock B, “Life cycle assessment: adopting and adapting overseas LCA data and methodologies for building materials in New Zealand”, New Zealand: Ministry of Agriculture and Forestry, 2008.

[22] Gonzalez MJ, Navarro JG. “Assessment of the decrease of CO_2 emissions in the construction field through the selection of materials: practical case studies of three houses of low environmental impact”, Journal of Building and Environment, Vol.41 (7), 2006, pp.902-9.

[23] P. Crowther, “Design for disassembly to recover embodied energy”, The 16th Annual Conference on Passive and Low Energy Architecture, Melbourne, Australia, 1999.

[24] Lenzen M., Treloar G, “Embodied energy in buildings: wood versus concrete”, Energy Policy, Vol.30, No. 3, 2002, pp.249–255.

[25] Sharrad AL, “Greening construction processes using an input-output-based hybrid life cycle assessment model”, Civil and Environmental Engineering, Carnegie Mellon University, Pittsburgh, Pennsylvania,USA,2010.

[26] Bullard C.W, Penner P.S, Pileti D.A., “Net energy analysis- handbook for combining process and I-O analysis”, Journal of Resources and Energy, Vol.1, 1978, pp.267-313.

[27] Shivaprasad K N, S Raghunath and Dhavala S, “Embodied energy and operating energy auditing of an institutional building”, 36th series of Student Project Programme 14, 2012, 68-69.

[28] Dixit MK, Fernández-Solís JL, Lavy S and Culp CH, “Identification of parameters for embodied energy measurement: a literature review”, Journal of Energy and Buildings, Vol.42 (8), 2010, pp.1238-47.

[29] UNEP, Buildings and Climate Change: status, challenges &opportunities, United Nations Environment Programme, 2007.

[30] Crawford, R.H., Czerniakowski, I., and Fuller, R., “A comprehensive framework for assessing the life-cycle energy of building construction assemblies”, Architectural science review, Vol. 53(3), 2010, pp.288.

[31] Treloar, G.J., Fay, R., Love, P.E.D., and Iyer-Raniga, U.,”Analyzing the life-cycle energy of an Australian residential building and its householders”, Journal of Building Research and Information, Vol. 28(3), 2000, pp.184–195.

[32] Rauf, A. and Crawford, R.H., “The relationship between material service life and the life cycle energy of contemporary residential buildings in Australia”, Architectural Science Review, Vol. 56(3), 2013, pp.252-261.

[33] Roger Fay, Graham Treloar and Usha Iyer-Raniga, “Life-cycle energy analysis of buildings: A case study”, Building Research & Information, 28(1), 2000, 31-41.

[34] Ramesh S P and Emran Khan M, “Energy Efficiency In Green Buildings – Indian Concept”, International Journal of Emerging Technology and Advanced Engineering, Volume 3, 2013, pp.329-336

[35] Jincheng Xing, Peng Ren, Jihong Lin, “Analysis of energy efficiency retrofit scheme for hotel buildings using e-Quest software: A case study from Tianjin, China”, Energy and Buildings, Volume 87, 2015, pp.14-24

[36] Luis Perez-Lombard, Jose Ortiz, Christine Pout, “A review on buildings energy consumption information”, Energy and Buildings, 40, 2008, 394–398.

[37] V S K V Harish and Arun Kumar, “A review on modelling and simulation of building energy systems”, Vol. 56, 2016, pp. 1272–1292.

[38] Hema Sree Rallapalli, “A comparison of Energy Plus and e-Quest whole building energy simulation results for a medium sized office building”, Arizona State University, 2010.

[39] Luisa F. Cabeza, Lidia Rincon, Virginia Vilarino, Gabriel Perez, Albert Castell, “Life cycle assessment (LCA) and life cycle energy analysis (LCEA) of buildings and the building sector: A review”, Journal of Renewable and Sustainable Energy Reviews, Vol.29, 2014, pp.394-416.

[40] Bekker P.C.F., “A life cycle approach in building”, Journal of Building and Environment, Vol.17 (1), 1982, pp.55-61.

[41] Adalberth K., “Energy use during the Life Cycle of single-unit dwellings”, Journal of Building and Environment, Vol.32, No.4, 1997, pp.321-329.

[42] Ciambrone DF, “Environmental life cycle analysis, New York”, Lewis, Boca Raton, 1997.

[43] Joshi S, “Product environmental life cycle assessment using input-output techniques”, Journal of industrial Ecology, Vol.2-3, 1992, pp.95-120.

[44] ISO, ISO 14040, Environmental Management, “Life Cycle Assessment Principles and Framework”, International Organization for Standardization, 1997.

[45] Lawson W, “LCA and Embodied Energy: some contentious issues.In: Proceedings of embodied energy seminar: current state of play, 1996.

[46] Ting SK, “Optimization of embodied energy in domestic construction”, Master of Engineering Thesis, RMIT, Australia, 2006.

[47] Khasreen MM, Banfill PFG, Menzies GF, “Life cycle assessment and the environment impact of buildings: a review”, Journal of Sustainability, Vol. 1(3), 2009, pp.674-701.

[48] Ajit Sabnis and M R Pranesh, Building Materials Assessment for Sustainable Construction Based on Figure of Merit as a Concept. *International Journal of Civil Engineering and Technology*, 8(2), 2017, pp. 203–217

[49] N. Tarun and N. Lokeshwaran, A Case Study on Assessing Energy Efficiency of Existing Residential Building and Recommendations Ensuring Green Efficiency in Building Construction Projects. *International Journal of Civil Engineering and Technology*, 8(3), 2017, pp. 921–927.